

Bringing Earthquakes Inside

An Honors Thesis (HONRS 499)

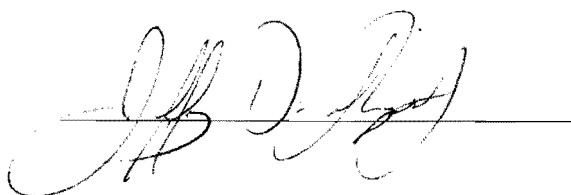
by

Lorelei La Violette

Thesis Advisors

Dr. Alan Samuelson

Dr. Jeff Grigsby

A handwritten signature in black ink, appearing to read "Alan Samuelson", is written over a horizontal line.

Ball State University

Muncie, Indiana

12/2004

Graduation Date: 12/2004

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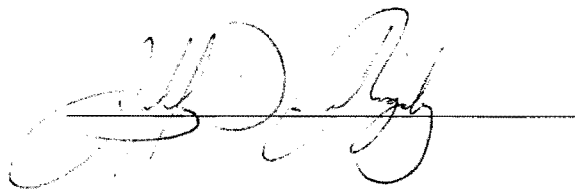
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Introduction

Earthquakes are an intriguing part of life, one that brings both excitement and fear. Scientists do what they can to learn more about these phenomena while cities and the people within them try merely to be prepared and survive through them. A moderate to strong magnitude (>5) earthquake occurs almost every year, inflicting damage on both structures and people. As a geologist, the mechanics and driving forces behind earthquakes are fascinating, and the information that scientists are able to deduce from them, impressive. This project was undertaken to explore the information that earthquakes can give us as well as to help spread knowledge about one of Earth's more elemental, and potentially deadly, processes. By studying and relating three recent earthquakes, information about the fundamentals of seismology was learned and then was applied to the specific aspect of comparing earthquake residuals to see what information could be derived from this data. Residuals are the difference in time between the actual wave arrival time at a seismology station and an estimated arrival time. With this information a GIS, Global Information Systems, map was created using the computer program ArcMap. The final aspect of this project included developing a lab that could be used in future Geology 101 classes that would make students more knowledgeable of the nature and characteristics of earthquakes.

From the outset, while researching the earthquakes and coming up with a way to teach others about earthquakes, this project was more than a one time study; it was an exploration of the future. The undergraduate Geology degree is a rather broad degree covering several aspects, for many geologists graduate school is a necessity to gain more expertise and experience in a specific field. By taking an in-depth look into seismology and earthquakes for this project, a better understanding of seismology has been gained, which has therefore helped to decide on whether or not to continue study in this field via graduate school. While other details pertaining to the project may have changed throughout the course of this semester, this has remained a fundamental part.

Originally this project involved research into seismograms (the records of earth movement during an earthquake), being able to read and interpret them and then merely writing up that information. As this project has progressed the focus has shifted more to comparing information from three separate earthquakes, specifically their residual data

and what this information could mean. This is what is represented through the ArcMap program. The 101 lab also was intended to have specific questions about recent earthquakes that would help the students relate to the information and so help them learn. As the lab was created, the focus became more to simply educate the students about the overall aspects of earthquakes and the many ways it could affect them. The lab still addressed specific details but more in a way to relate the student to their Earth as a whole. It was decided that developing a residual map as well as a 101 lab would make for a very good project. Through the research and study, it would be possible to further scientific study and prepare for a future in graduate school, as well as for a career, while the lab section would give something back to the Geology department.

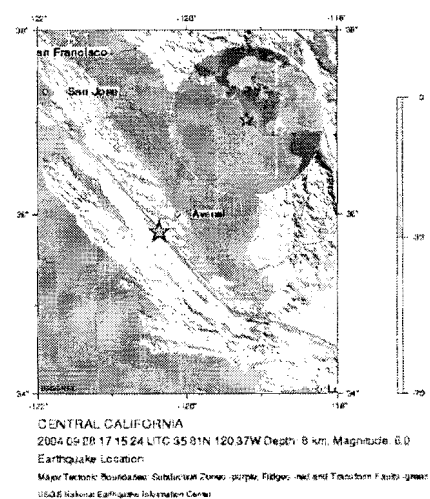
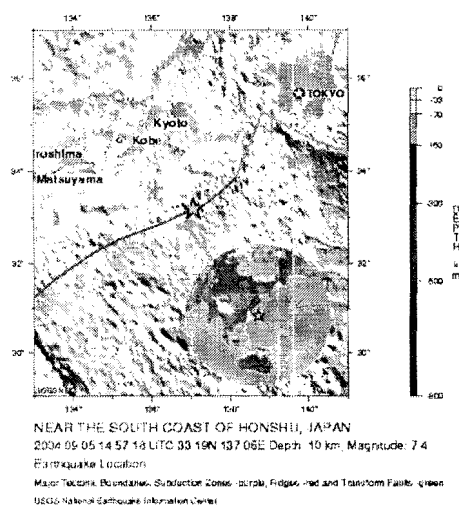
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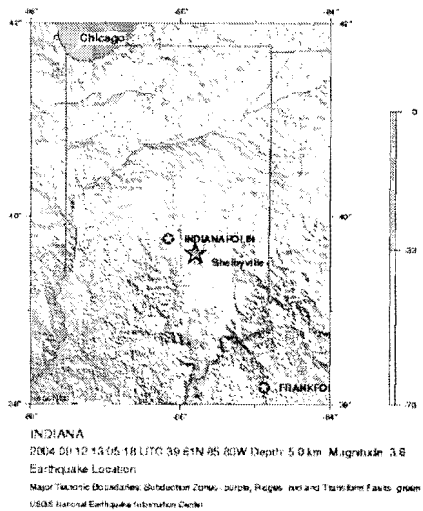
The beginning of the project focused mainly on reading and study. Three texts were studied in order to develop a good seismological foundation. They were: *Elementary Seismology* by Charles Richter, *Whole Earth Geophysics* by Robert Lillie and finally *Earthquakes and Geological Discovery* by Bruce Bolt. Upon reading these books the theory behind much of the work done with seismology became clearer. Also, the basic language of seismology was learned, such as the different wave types and the nomenclature for all the possible combinations of waves, which may be read by a seismograph. It also became evident that while basic interpretations may be done relatively quickly when viewing a seismogram (such as primary and secondary wave arrivals, distance to the epicenter and perhaps a rough estimate of magnitude) more in-depth interpretations take time to examine and often require an experienced eye in order to correctly interpret the data. This affected the course of the project in that the focus shifted from looking only at a few seismograms to comparing information from different earthquakes.

To start off, data was received from a seismograph at Muncie Central High School for the September 12, 2004 earthquake centered at Shelbyville, Indiana, which registered at a 3.6 on the Richter scale. This data was in the form of three standard seismograms, two of which measured the displacement horizontally from East to West and from North to South while a third measured vertical displacement. This same data

was also retrieved from the Bloomington, Indiana seismograph station in order to see how the results differed. Preliminary analysis was done on the two data sets however, due to the change in focus, no in-depth study was done with the seismograms. At this time the GIS project, focusing on residuals, began to take shape as a primary aspect of the project and the residual data needed was taken from the datasets of the United States Geological Survey via their website, www.usgs.gov.

The residual aspect of the project came up as information (magnitude, primary wave arrival times, etc.) was being obtained on three different earthquakes. The earthquakes included the Shelbyville, IN earthquake, the September 28, 2004 6.0 earthquake which occurred near Parkfield, California, and the September 5, 2004 earthquake off the south coast of Honshu, Japan which measured a 7.4 for magnitude. The location of each earthquake can be seen in the following maps, all of which are courtesy of the USGS and can be found at their website www.usgs.gov. Along with wave arrival times for various seismograph stations for each of these earthquakes, the USGS website also includes residual data for most of the stations. When first going through this information it was interesting to consider how the residual data might compare for each of the earthquakes and selected seismograph stations and what this may reveal about the Earth and rock through which the waves were passing through. It was discussed that not much work had been done with residuals and so the idea to focus on the residual data for each of the earthquakes solidified.





Once the idea had been decided upon, the necessary data was gathered and put it into formats that could be used by the ArcMap program. The latitude and longitude coordinates for the three earthquake epicenters as well as for a set group of seismograph stations (mostly ones that had data from all three earthquakes) were obtained and placed into an excel spreadsheet and then saved as a database file so that the information could be added to ArcMap. Since the exact bearing from the earthquake epicenters to the specific stations

was not known it was necessary to merely draw in lines connecting the epicenters to the stations and then type in the residual information for each line.

This was the basis for the next step, which would be to contour the residuals. A contour line connects areas of equal values and was used in this case to connect the dots, as it were, of equal residual values. Residuals are determined by a complex system of equations that take various factors, such as the type of rock the wave is moving through, into consideration. This exercise is to determine if bedrock or surface material may be a cause for higher residuals. The residual values come as either positive or negative values, the sign is merely an indication of whether the wave was faster (positive) or slower (negative) than the predicted wave, the important part is the number itself and how different it is from the predicted value. The residuals were contoured based on value and not on positive and negative. Once contours had been drawn in for each of the earthquakes values (data was more limited for the California earthquake and so the contours were done off the information at hand) then the contours were compiled onto one map to see if there was any relationship.

While developing the ArcMap portion, work was also being done to construct a lab that could be used in the Geology 101 lab curriculum. The department Chair had been collecting material pertaining to earthquake labs in the hopes of one day creating one and so this material was studied as development of the lab began. The material that had been collected included such things as current labs available online and labs

developed by other people on the subject of earthquakes. Upon going through the material it was realized that much of the more detailed and scientific aspects of the labs would never again be used by many of the students and so was not really relevant to them. It was felt that the lab should focus on more general material such as awareness of the processes at work during earthquakes, the driving forces of earthquakes and how they are related to the Earth as a whole, giving the student a better overall understanding of the Earth and how it worked. Exercises were included that would increase the student's scientific understanding of earthquakes and some of the techniques used by scientists in regards to earthquakes. However, the lab overall is more environmentally focused rather than scientifically focused, that is, focused more on how earthquakes are an inherent part and process of Earth and how they affect everyday people as opposed to being focused more on the scientific interpretations of seismograms.

Some changes were made as the lab was developed from the original plans and intentions. One of the main ways that was planned on being used to relate the material to the students was by having the students do an exercise and analyze information from an earthquake that had happened recently and with which they may already be familiar with. As the lab progressed it became apparent that it would be rather difficult to construct a specific exercise reflecting the exact information from an earthquake. First off extensive searching and developing would be needed to get accurate information and present it in an appropriate style and secondly the students would most likely be able to get the exact information off the Internet. While the lab does require students to look up various websites in order to find answers, the larger exercises were hand-made so that the exact answers could not be looked up on the Internet. Also, even though it would be desired to change the specific earthquake that was focused on year to year, this would naturally indicate that the lab itself would need to change year to year or every two years. This would require a lot of an individual's time from someone who may not have the time or may not be familiar enough with the labs and its goals in order to adequately adapt it year to year. It is possible that if this lab were to grow in its importance within the 101 lab structure then such a feature within it would be very desirable and very worth the extra work. For now though the basics behind earthquakes should be sufficient to cover the needed information.

Results

The seismograms produced no real results as only preliminary studies were done such as locating the p- and s-wave time intervals. These intervals are marked on the attached seismograms. Further information was not obtained as it was outside the scope of this project.

Some trends were discovered from the maps created through ArcMap, which related the residual values of each earthquake. It was noticed that certain geographical areas seem to have similar values with an overall trend of higher residuals being found more toward the margins of the continent. Regional circles were drawn in to represent the trend of the data. A world map with the earthquake and seismograph station locations along with three maps showing the contoured residuals for each earthquake and finally the overall combined residual values are all shown on the ArcMap layout. All of these maps follow this report.

Wave speeds, and therefore the residual calculations, are dependent on the material the wave is passing through. The bedrock and materials covering the United States are highly variable and intricate. However, as a broad generalization, the U.S. has mountain ranges to both the East and the West and a general basin structure around the Midwest. It is possible that the mountains, with more metamorphosed and fractured rock, may be affecting the waves much more dramatically than originally calculated. The central basin and its rock and sediments were probably easier to calculate accurate wave speeds due to their rather continuous nature. Also it is easier to test and do studies in flatter areas with more predictable ground material. In the mountains, with the very disrupted nature of the material, as well as the more challenging aspect of testing in such rugged terrain, it would be more difficult to determine accurate wave speeds across the area. The ground material would be more important for the California and Indiana cases though not as important for the Japan earthquake. This is because as seismograph stations get further and further away from the epicenter of an earthquake, this allows more time for seismic waves to travel down into the mantle of the Earth instead of merely through the crust. Waves that travel through the mantle spend most of their time there and the effect of crustal material on the wave speed diminishes. In these instances

residuals are more likely to be a result of the difficulty of accurately predicting long-distance travel speeds, as there is more time for interference. As can be noted in the following map of the Japan earthquake, in general the higher residuals are further away from the epicenter.

As for the lab that was developed for Geology 101 classes, results cannot really be obtained until the lab has been put into use. The lab itself is attached separately, as are the answers, which would be a guide to the Geology 101 lab teaching assistants when they grade these exercises. The basic information conveyed was meant to progress from the driving influences and factors of earthquakes to their mechanical operation and finally to the effects that earthquakes have on humans and life in general. The format chosen to present this information mirrors the format of another lab that was developed by Chuck Betz, a geology doctoral student, and is already in use in the 101 labs. His lab drew from an online program that students must complete and focuses on the Earth's reserves of natural resources. This seemed to be an ideal format as this way the students can be assigned the lab as a take-home project and so no time is taken from the curriculum already in place while at the same time reinforcing some of the concepts being taught, hopefully making them easier to understand. Also the students can finish this lab at their leisure unlike some of the other labs that require the students to use materials only available in the Geology department.

Summary

Originally this project was to focus on the interpretation of seismograms from specific earthquakes. As research was done however it was found that to focus entirely on seismograms would be fairly limited and would not necessarily result in a good interpretation due to the experience needed to accurately interpret seismograms. From this it was decided to instead focus on available data from three specific recent earthquakes and compare them. Upon looking at the data it was found that residual values were not well studied and since there was an adequate amount of residual information it was decided to compare this particular aspect of the earthquakes to see if any conclusions could be made about the material through which the waves were traveling.

Residual data was gathered and compiled into several maps using the computer program ArcMap. From this determinations could be made as to the most likely cause for higher differences between calculated and actual wave arrival times. The development of the maps also allows for the presentation of this information to other scientists.

A laboratory exercise for a Geology 101 class was developed after being decided that this would be a good way to educate regular people about the causes and nature of earthquakes. By referencing other labs developed on earthquakes, as well as lab formats in general, a basic environmental earthquake lab was created. The lab focuses on aspects of earthquakes that are likely to be important for non-geologists in their everyday lives. By implementing the exercise in the upcoming semesters conclusions can be made as to whether the lab was an effective teaching aid.

Conclusions

Residual trends are rather interesting aspects of earthquakes and are a representation of our understanding of seismic waves. While scientists know the general information affecting the travel of seismic waves, there is still quite a bit of room for further research. Predicting the waves arrival time is fairly straightforward as we know many of the involved factors, however the detail with which the wave arrivals are predicted is much harder as that requires detailed knowledge of all the factors which is something that is still being improved daily (www.usgs.gov). The information represented on the map layout is a start for further investigation. While this study is small and minor compared to many of the large ongoing earthquake studies, it is still a good starting point for an aspect of seismic waves that does not get much attention. It would be very interesting to see what further studies and comparisons would reveal. Also there is room to explore the other aspects that affect the estimated wave arrival times and together with this data would provide an overall more accurate view of what needs to be done to more accurately predict wave arrival times.

Developing a lab for use in a Geology 101 course has provided a unique challenge as to how to convey scientific geology information to non-geologists. Various ideas were considered and an evaluation of the material to be taught was needed in order to

effectively design the lab. By having the lab exercise focus mainly on more environmental and basic features of earthquakes it is hoped that students will be taught aspects that are more important to them and so will result in students taking away relevant information that will stay with them in the future.

Several changes and adjustments have been made to this project throughout the semester and while this is a normal developing process, it is still felt that the initial goal and intent of this project has been accomplished. Having done quite a bit of study and research on earthquakes and seismic waves, this project has greatly increased personal preparation and capability for future work in this field. The map that has been produced looks at one aspect of earthquakes that had not been initially considered due to ignorance of the subject but has now developed into an integral part of this project, furthering knowledge on the subject. The lab that was developed is the part of the project that passes on the knowledge that was gained to others to whom this information has some real relevance as they live and travel around the planet. It is believed that the lab will successfully convey the information to the students but only practical application will really be able to tell and there is great anticipation to the implementation of this lab in the upcoming semesters. While this has not been a standard research project it has still created a chance to explore an area of geology that would not have been readily available to an undergraduate.

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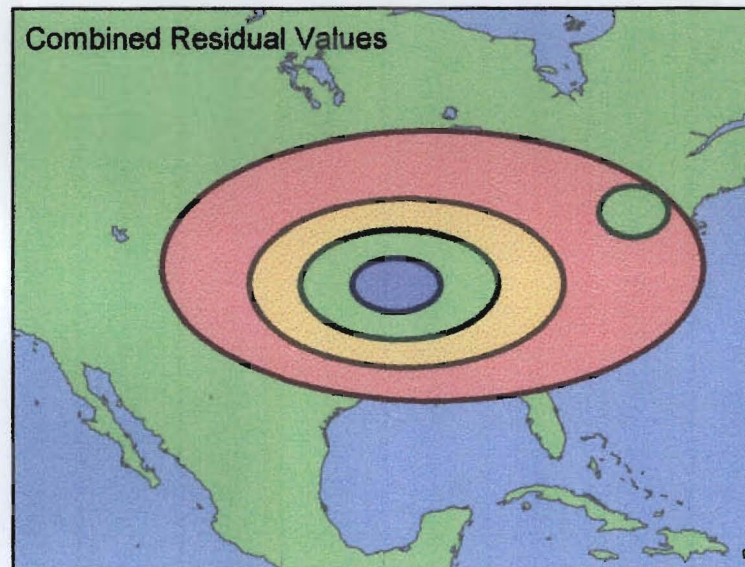
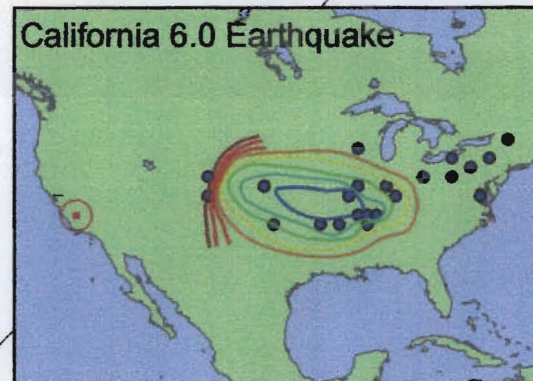
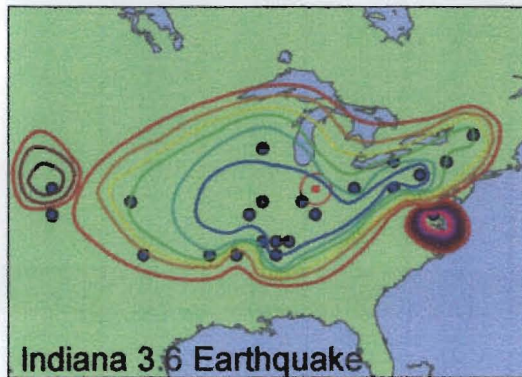
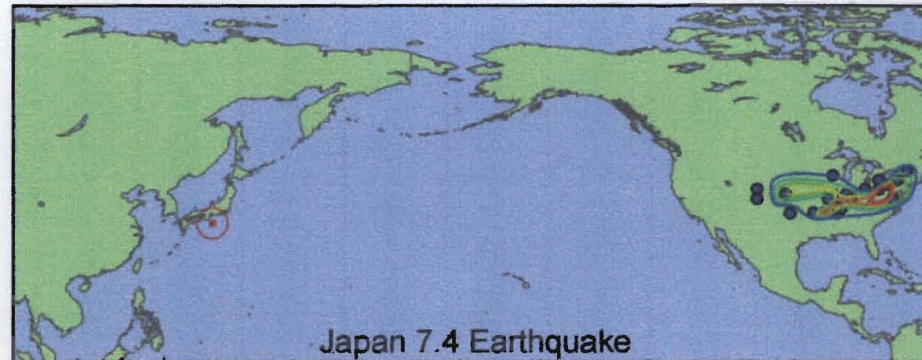
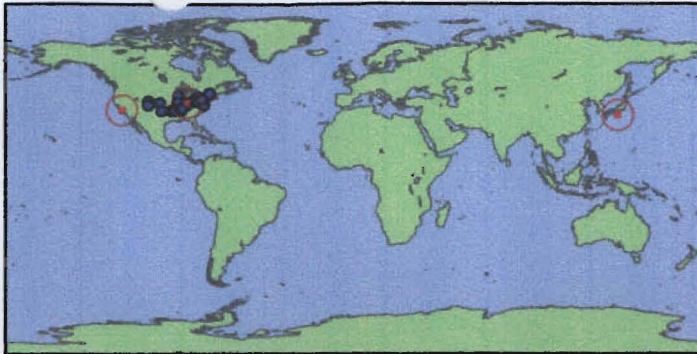
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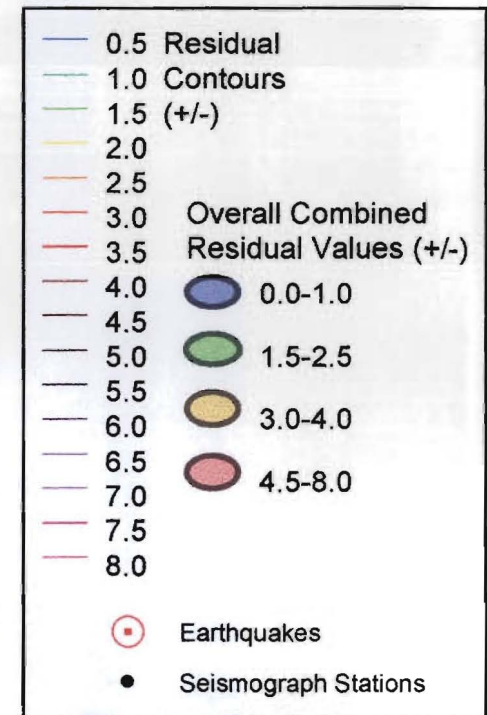
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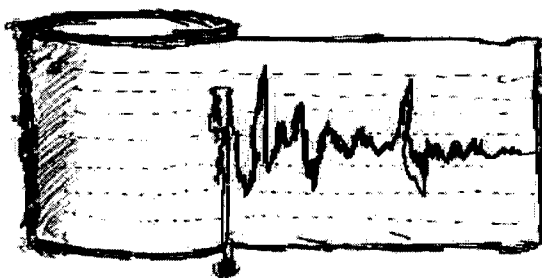
Earthquake Residuals

A residual is the time difference between an observed signal arrival time and a theoretically predicted arrival time.
A contour line marks areas of equal values, in this case, of equal residual values.



The end map shows that residual values overall increase as one moves towards the edges of the United States. This implies that conditions along the boundaries do not agree with the predetermined conditions used to calculate earthquake arrival times. While this cannot pinpoint the exact causes for the higher residuals, it does provide a guide that, with more study and comparison, may lead to a regional pattern of higher and lower residuals.





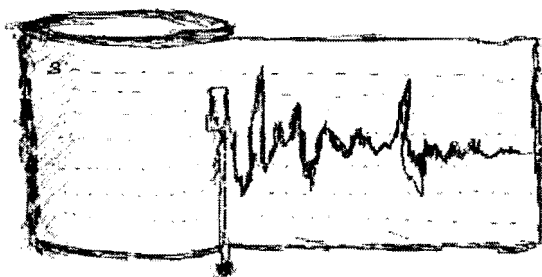
Earthquake Lab Overview

Objectives:

- To increase the students' understanding of the processes and factors which cause and are related to earthquakes.
- To familiarize students with the aspects of earthquakes which are most likely to affect their lives.

Materials needed:

- Printed copy of the worksheet
- 101 textbook: Intro to Environmental Geology, Edward A. Keller, second edition
- Internet access
- Ruler
- Compass for drawing circles



Earthquake Lab Worksheet

Name: _____

Print off this worksheet and turn the completed form in to your lab instructor.

Using your textbook and previous knowledge answer the following questions:

What is a tectonic plate?

What is a fault?

What is an earthquake?

This lab will be focusing on those three aspects and will address: how they're related, what they tell scientists and how they affect you. The following questions have links to associated websites so make sure you have internet access when doing this lab. A ruler and compass will also be useful.

<http://pubs.usgs.gov/publications/text/tectonic.html>

Do tectonic plates change over time? _____

In what way? _____

Name one of the two largest plates. _____

101 textbook sections 5.4 and 5.5

<http://pubs.usgs.gov/gip/earthq1/where.html>

<http://pubs.usgs.gov/publications/text/understanding.html>

What are the three types of plate boundaries? _____

Give real world examples of each type. _____

Do most earthquakes occur at plate boundaries or plate interiors? _____

What causes earthquakes in plate interiors? _____

www.crustal.ucsb.edu/ics/understanding/elastic/intro-rebound.html

View animation

What is the elastic rebound theory and how does it relate to fault movement? _____

www.tinynet.com/faults.html

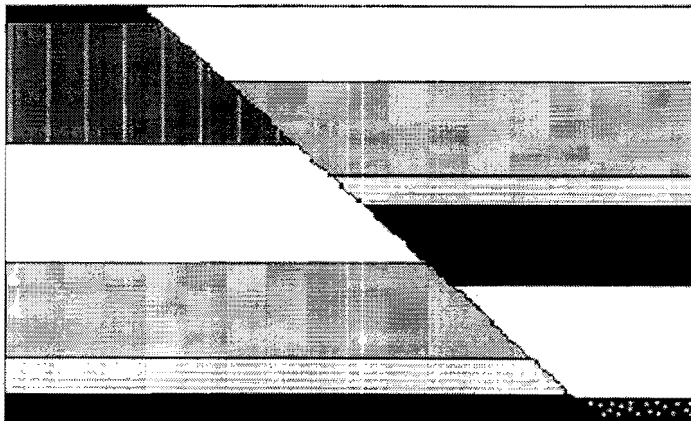
<http://scign.jpl.nasa.gov/learn/plate6.htm>

Normal faults are associated with crustal _____ and occur at _____ plate boundaries.

Reverse faults are associated with crustal _____ and occur at _____ plate boundaries.

Strike-slip faults are associated with _____ motion of crust and occur at _____ plate boundaries.

Block Diagram



0 50 100 m

What is the offset of the fault in meters?

_____m

What type of fault is this?

What type of stress is responsible for this fault?

Where can this kind of fault be found in the world?

<http://earthquake.usgs.gov/4kids/facts.html>

At what depths do most earthquakes occur? _____km _____mi

What is the most earthquake prone state? _____

What is the difference between the focus (hypocenter) and the epicenter of an earthquake? _____

Where was the largest earthquake in the world since 1900? What was its magnitude and when did it occur? _____

What does the magnitude of an earthquake measure? _____

What does the intensity of an earthquake measure? _____

At what kind of plate boundary do the deepest earthquakes occur most often? _____

101 Textbook Section 5.10

<http://www.umich.edu/~gs265/society/earthquakes.htm>- Aftershocks section

Name three deadly secondary effects of earthquakes? _____

<http://www.geo.mtu.edu/UPSeis/intensity.html>

Which is more scientifically accurate: the Mercalli or the Richter scale? Why? _____

The difference between each whole number on the Richter scale represents how much of a strength difference? _____

The amount of ground shaking increases by how much when you move from a magnitude 2 earthquake to a magnitude 5 earthquake? _____

About how many 2.5-5.4 magnitude earthquakes occur every year? _____

An earthquake with an intensity of XI is roughly equal to what magnitude earthquake? _____

www.geo.mtu.edu/UPSeis/waves.html

<http://www-rohan.sdsu.edu/~rmellors/lab8/l8maineq.htm>

Name the two main types of seismic waves and give two examples of each. _____

Which type of waves cause the most damage? _____

Which wave is the first to arrive after an earthquake? _____

How do geologists know from seismic waves that the Earth's outer core is fluid? _____

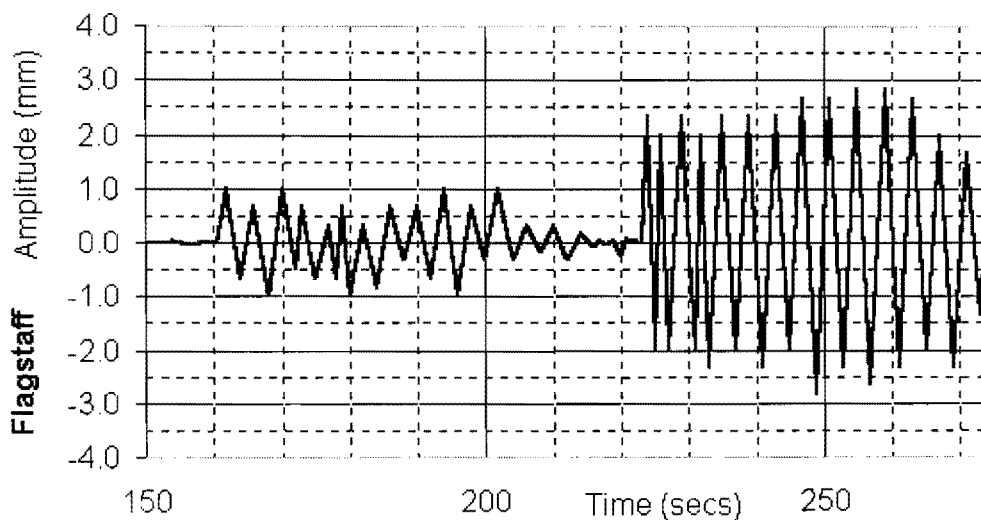
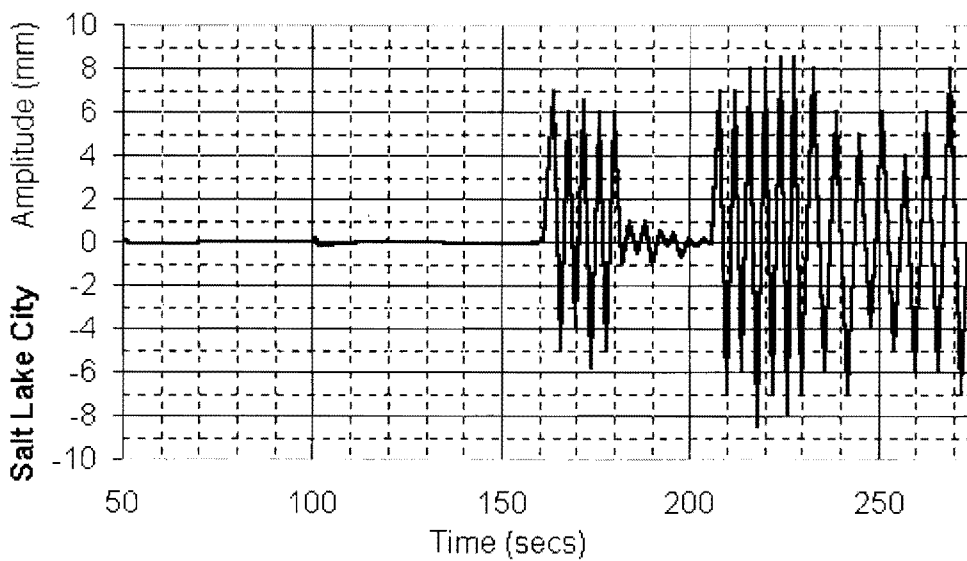
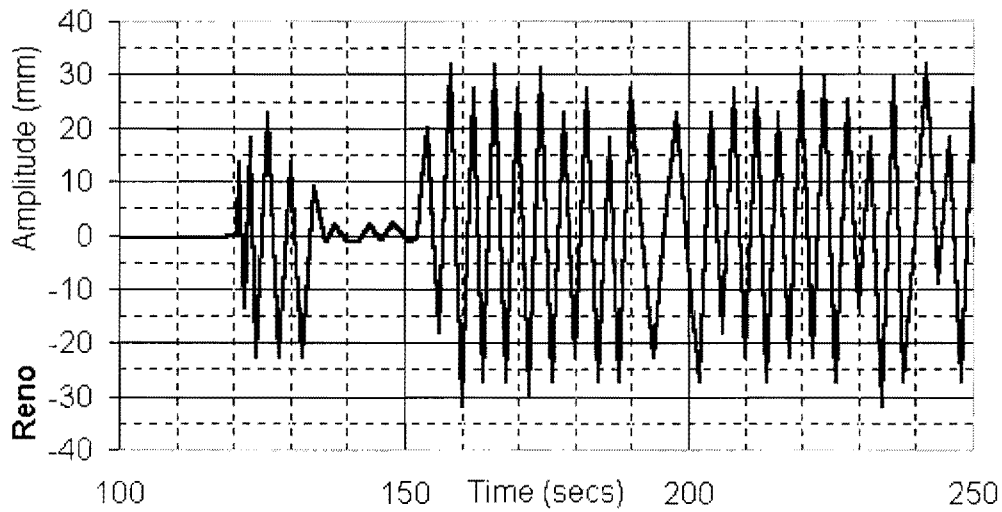
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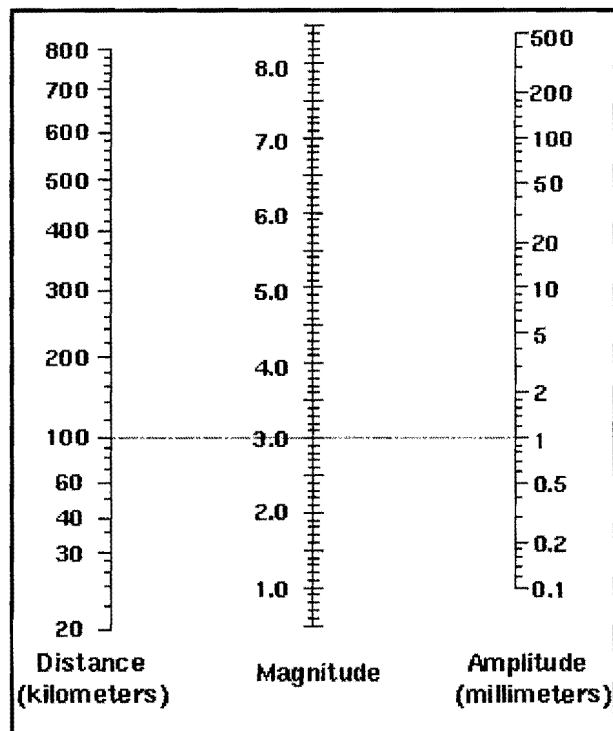
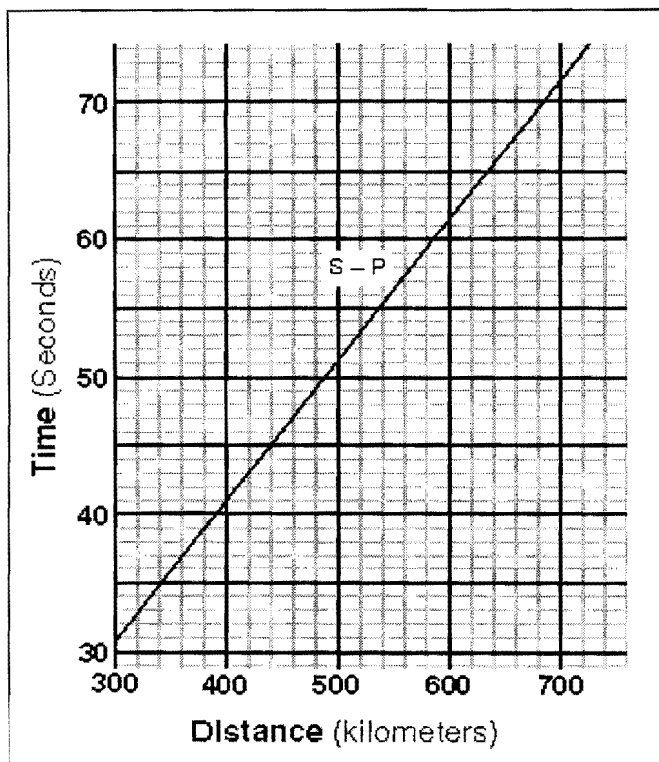
<http://www-rohan.sdsu.edu/~rmellors/lab8/l8maineq.htm> -Locating Earthquakes With Seismic Waves section

Locating the epicenter of an earthquake:

For the following exercise you are given three seismograms and a map with the seismograph locations. Find the S-P intervals, as well as the amplitude, for each graph and use that information to locate the earthquake epicenter.

Seismograms





Reno

S-P (sec) _____

Amplitude (mm) _____

Distance (km) _____

Salt Lake City

S-P (sec) _____

Amplitude (mm) _____

Distance (km) _____

Flagstaff

S-P (sec) _____

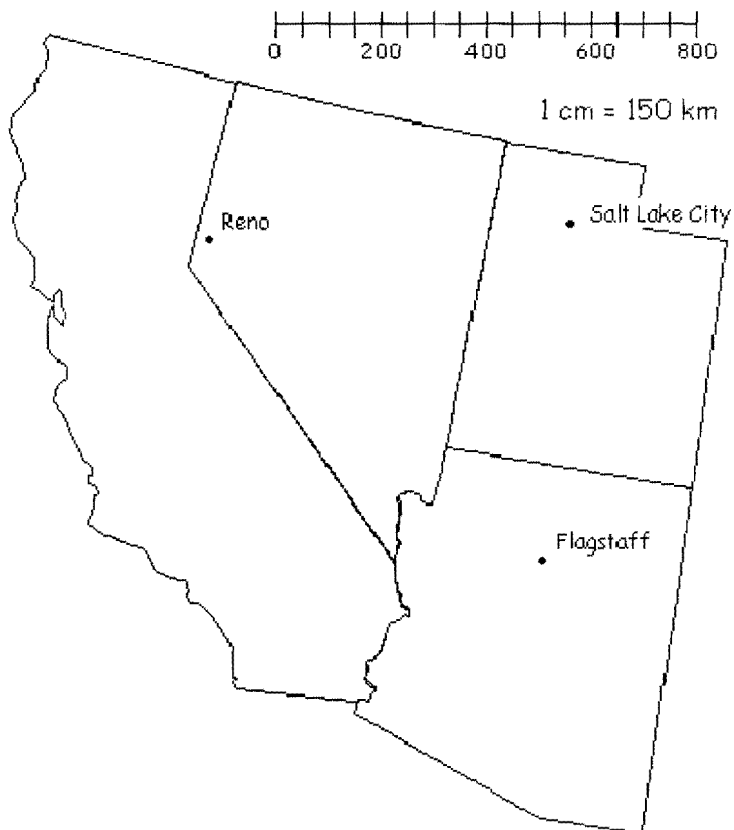
Amplitude (mm) _____

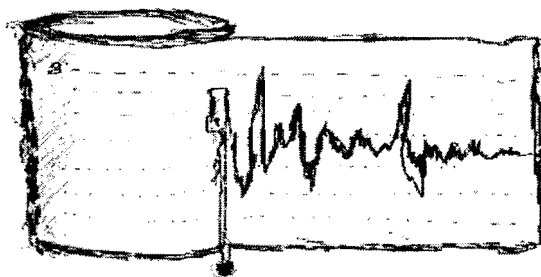
Distance (km) _____

Overall magnitude of earthquake _____

Mark the epicenter with a star.
Show all your work.

What factor, that we have not considered above, could cause our earthquake location to be slightly off? _____





Earthquake Lab Worksheet

Name: _____

Print off this worksheet and turn the completed form in to your lab instructor.

Using your textbook and previous knowledge answer the following questions:

What is a tectonic (or lithospheric) plate?

Broken pieces of the lithosphere that move relative to one another. May include a continent and part of an ocean basin or an ocean region alone.

What is a fault?

Fractures in the Earth along which the rock on one side slides past the rock on the other side.

What is an earthquake?

Natural shaking or vibrating of the Earth in response to the breaking of rocks along faults.

This lab will be focusing on those three aspects and will address: how they're related, what they tell scientists and how they affect you. The following questions have links to associated websites so make sure you have internet access when doing this lab. A ruler and compass will also be useful.

<http://pubs.usgs.gov/publications/text/tectonic.html>

Do tectonic plates change over time? Yes

In what way? Plates may be subducted under other plates and be destroyed (or they may grow due to the addition of crust at spreading ridges. This last part is not mentioned on the website however it is a correct answer.)

Name one of the two largest plates. Pacific and/or Antarctic Plates

101 textbook sections 5.4 and 5.5

<http://pubs.usgs.gov/gip/earthq1/where.html>

<http://pubs.usgs.gov/publications/text/understanding.html>

What are the three types of plate boundaries? Convergent (or Subduction), Divergent (or Spreading) and Transform Boundaries

Give real world examples of each type. Some examples- Convergent: NW coast of U.S.A., western Canada and southern Alaska and Aleutian Islands Divergent: Mid-Atlantic Ridge Transform: San Andreas Fault

Do most earthquakes occur at plate boundaries or plate interiors? _____

Most earthquakes occur at plate boundaries

What causes earthquakes in plate interiors? Plate boundaries change over time and old, weakened boundaries may become part of the interior of a plate causing a zone of weakness along which earthquakes may occur.

www.crustal.ucsb.edu/ics/understanding/elastic/intro-rebound.html

View animation

What is the elastic rebound theory and how does it relate to fault movement? The theory is that stress in rocks builds up over time and slowly distorts the ground until the strain is too great causing the rock to suddenly snap or break, relieving the pressure. When the rock breaks, this is what causes an earthquake. This constitutes most of fault movement as the movement rate overall is usually measuring the slow distortional movement though during earthquakes the fault movement is sudden and much more extreme.

www.tinynet.com/faults.html

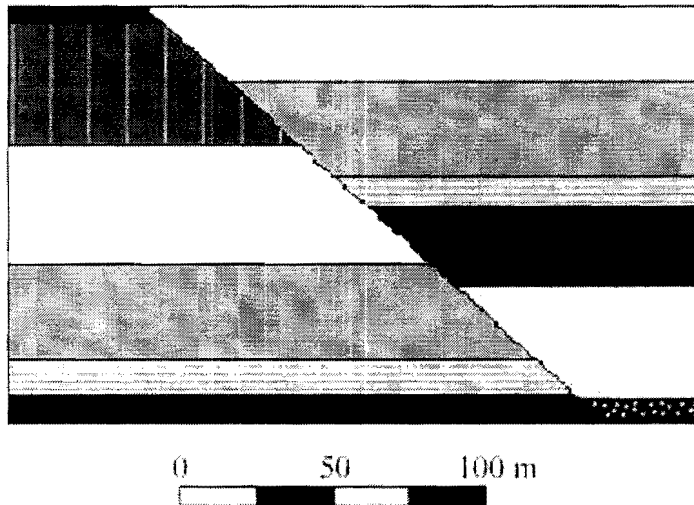
<http://scign.jpl.nasa.gov/learn/plate6.htm>

Normal faults are associated with crustal extension and occur at diverging plate boundaries.

Reverse faults are associated with crustal shortening and occur at converging plate boundaries.

Strike-slip faults are associated with lateral motion of crust and occur at transform plate boundaries.

Block Diagram



What is the offset of the fault in meters?

85-90 m

What type of fault is this?

reverse (or thrust)

What type of stress is responsible for this fault?

compressional

Where can this kind of fault be found in the world?

Rocky Mts., Himalayans, etc. (from above links- Sierra Madre Fault and Hebgen Lake, Montana)

<http://earthquake.usgs.gov/4kids/facts.html>

At what depths do most earthquakes occur? <80 km <50 mi

What is the most earthquake prone state? Alaska

What is the difference between the focus (hypocenter) and the epicenter of an earthquake? The focus of an earthquake is the point under the Earth's surface where the earthquake rupture began. The epicenter is located directly above the focus and marks on the Earth's surface where the earthquake rupture began.

Where was the largest earthquake in the world since 1900? What was its magnitude and when did it occur? Chile. 9.5 Mw. May 22, 1960

What does the magnitude of an earthquake measure? The value of an earthquake's size. This value does not change with distance.

What does the intensity of an earthquake measure? The amount of shaking caused by the earthquake. This value does change with location.

At what kind of plate boundary do the deepest earthquakes occur most often? Convergent boundaries

101 Textbook Section 5.10

<http://www.umich.edu/~gs265/society/earthquakes.htm>- Aftershocks section

Name three deadly secondary effects of earthquakes? Tsunamis, fires liquefaction, landslides, disease, ground cracking

<http://www.geo.mtu.edu/UPSeis/intensity.html>

Which is more scientifically accurate: the Mercalli or the Richter scale? Why? The Richter scale. The amount of shaking may be disagreed upon or not accurately reported and also the amount of shaking may not accurately reflect the size of the earthquake.

The difference between each whole number on the Richter scale represents how much of a strength difference? Ten times

The amount of ground shaking increases by how much when you move from a magnitude 2 earthquake to a magnitude 5 earthquake? 1,000

About how many 2.5-5.4 magnitude earthquakes occur every year? 30,000

An earthquake with an intensity of XI is roughly equal to what magnitude earthquake? 8

www.geo.mtu.edu/UPSeis/waves.html

<http://www-rohan.sdsu.edu/~rmellors/lab8/l8maineq.htm>

Name the two main types of seismic waves and give two examples of each. Surface waves: Rayleigh and Love Body Waves: P- and S-waves

Which type of waves cause the most damage? Surface waves

Which wave is the first to arrive after an earthquake? The P-wave

How do geologists know from seismic waves that the Earth's outer core is fluid? S-waves do not travel through fluids because fluids have no shear strength and no s-waves have traveled through the outer core.

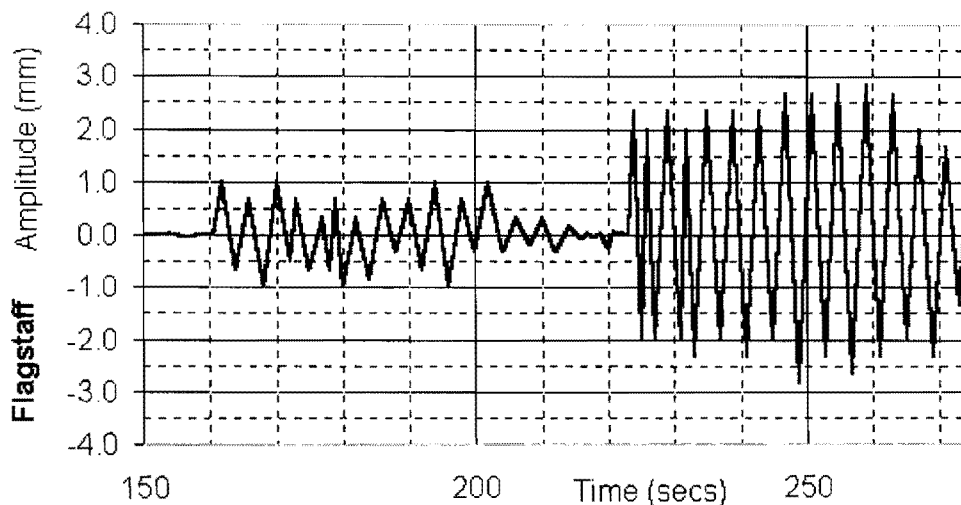
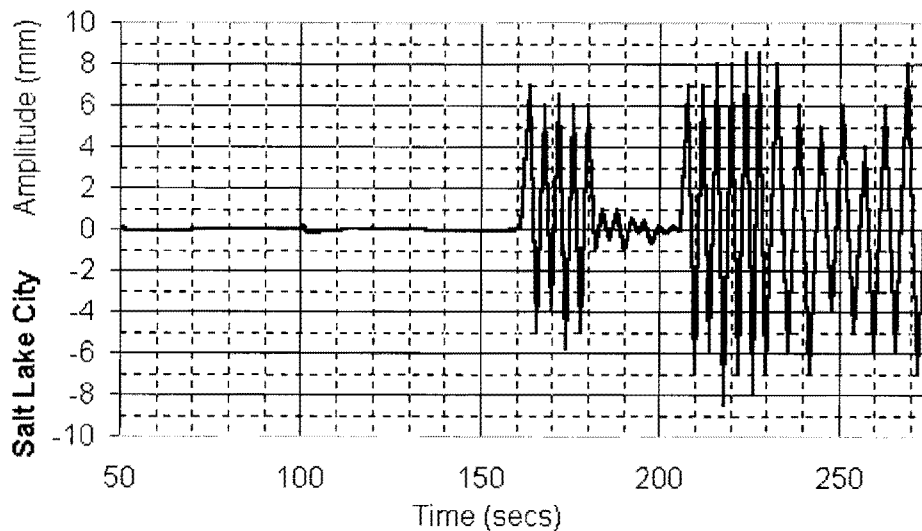
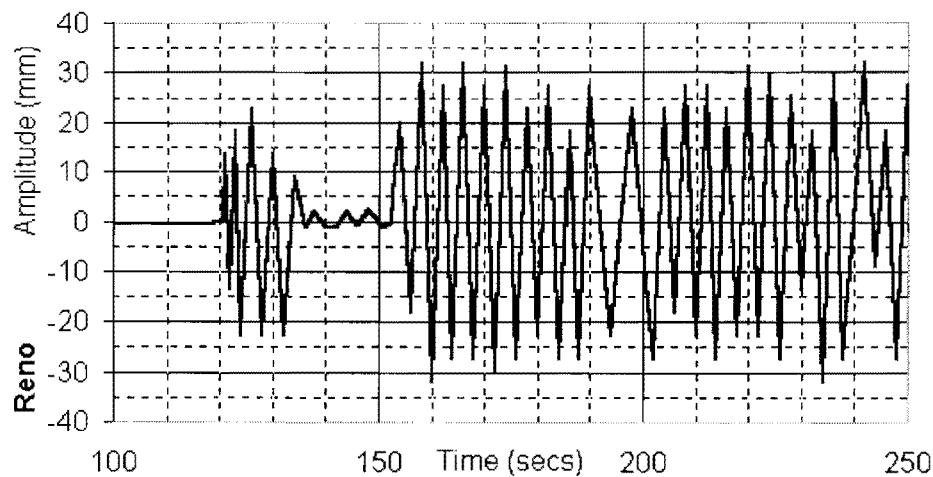
<http://www.geo.mtu.edu/UPSeis/locating.html>

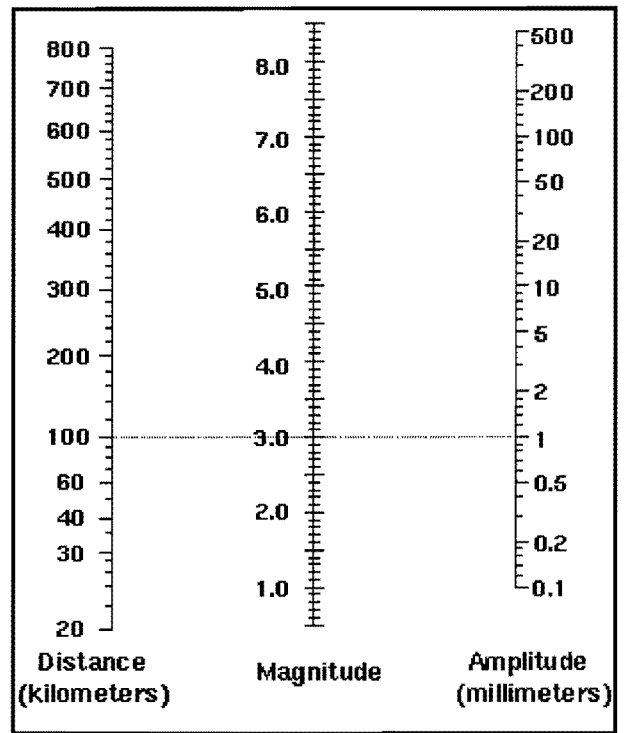
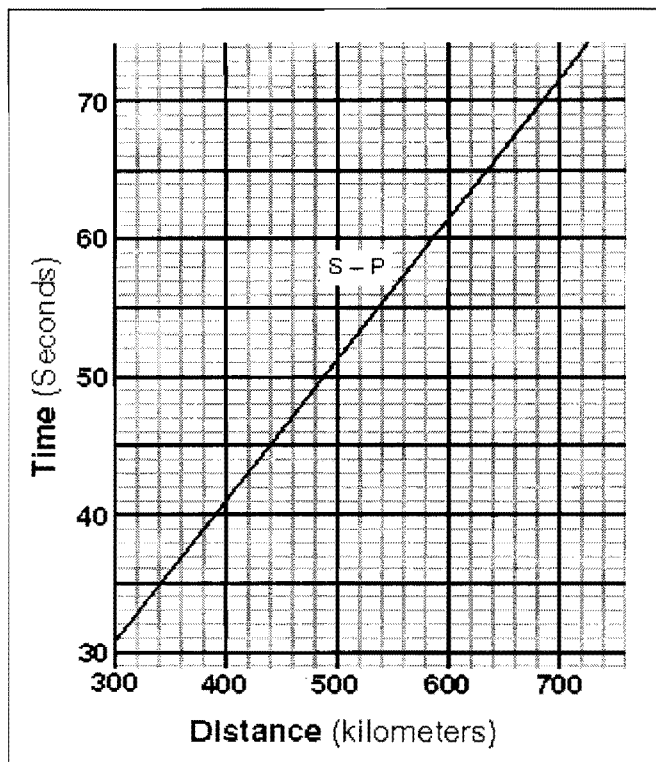
<http://www-rohan.sdsu.edu/~rmellors/lab8/l8maineq.htm> -Locating Earthquakes With Seismic Waves section

Locating the epicenter of an earthquake:

For the following exercise you are given three seismograms and a map with the seismograph locations. Find the S-P intervals, as well as the amplitude, for each graph and use that information to locate the earthquake epicenter.

Seismograms





Reno

S-P (sec) 32 Range(30-35)
 Amplitude (mm) 32 (30-34)
 Distance (km) 310 (300-340)

Salt Lake City

S-P (sec) 45 Range(40-50)
 Amplitude (mm) 9 (8-9)
 Distance (km) 440 (390-490)

Flagstaff

S-P (sec) 62 Range(60-65)
 Amplitude (mm) 2.8 (2.5-3.0)
 Distance (km) 610 (580-640)

Overall magnitude of earthquake 5.5 (5.2-5.8)

Mark the epicenter with a star.
 Show all your work.

What factor, that we have not considered above, could cause our earthquake location to be slightly off? The depth of the earthquake

